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RESEARCH MEMORANDUM

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DYNAMIC LONGITUDINAL STABILITY AND CONTROL OF TANDEM-COUPLED BOMBER-FIGHTER AIRPLANE MODELS WITH RIGID AND PITCH-FREE COUPLINGS

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DYNAMIC LONGITUDINAL STABILITY AND CONTROL OF TANDEM-COUPLED BOMBER-FIGHTER AIRPLANE MODELS WITH RIGID AND PITCH-FREE COUPLINGS

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SUMMARY

An experimental investigation has been made in the Langley free-flight tunnel to determine the dynamic longitudinal stability and control characteristics of tandem-coupled bomber-fighter airplane models. The investigation consisted of model flight tests of a rigidly coupled combination, of a freely coupled combination in which the models had relative freedom in pitch, and of the bomber model alone. The models used in the investigation were simplified models for which the weight of the bomber was about 10 times that of the fighter. The coupled combinations were flight tested for a range of bomber center-of-gravity locations varying from approximately 0 to 0.30 mean aerodynamic chord ahead of the bomber aerodynamic center.

The model flight tests showed that, for any given bomber center-of-gravity position, the dynamic stability and control of the freely coupled combination was as good as that of the bomber alone but that dynamic stability and control of the rigidly coupled combination was definitely inferior to that of either the freely coupled combination or the bomber alone. In fact, the rigidly coupled combination was violently unstable over a wide range of bomber center-of-gravity positions for which the freely coupled combination and the bomber alone were stable. Analyses of force-test data for the model indicate that the reason that the dynamic behavior of the rigidly coupled combination was less satisfactory than that of the bomber alone was that, for any given bomber center-of-gravity location, the downwash of the bomber on the fighter caused a reduction in static stability of the combination. Because of this downwash, the aerodynamic center did not move as far rearward as the center of gravity when the fighter was coupled to the bomber.

INTRODUCTION

One configuration being considered by the armed services in studies of means of extending the range of existing airplanes consists of a fighter coupled in tandem behind a bomber or tanker. The purpose of this coupled-airplane configuration is to increase the range of escort fighters by refueling them in flight or by carrying them as parasites. In order to determine the dynamic longitudinal stability and control of such a configuration, flight tests were made in the Langley free-flight tunnel with two coupled-airplane combinations: (1) a rigidly coupled combination, and (2) a freely coupled combination in which the models had relative freedom in pitch. For each of these combinations and for the bomber model alone, flights were made in which the bomber center of gravity was moved rearward in progressive steps from the 0.15-mean-aerodynamic-chord station of the bomber wing to the position for which the model was unflyable. Force tests were made with the bomber and fighter models alone and with the rigidly coupled combination in order to provide static stability data for use in the analysis of the flight-test results.

SYMBOLS

S	wing area, square feet
$\bar{c}$	wing mean aerodynamic chord, feet
V	airspeed, feet per second
ρ	air density, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
C_L	lift coefficient (Lift/qS)
C_D	drag coefficient (Drag/qS)
C_m	pitching-moment coefficient (Pitching moment/$qS\bar{c}$)
$\partial C_m/\partial C_L$	rate of change of pitching-moment coefficient with lift coefficient
α	angle of attack of longitudinal body axis, degrees

Subscripts:

b bomber model

f fighter model

APPARATUS

All the tests were made in the Langley free-flight tunnel which is described in reference 1. Force-test data were obtained from the free-flight-tunnel six-component balance which is described in reference 2.

A sketch of the coupled models is given in figure 1 and physical characteristics of the models are listed in table I. Although the models used in the investigation were simplified models which did not represent any particular full-scale configuration, the ratio of the weight of the bomber to that of the fighter (10 to 1) was fairly representative of some configurations presently under consideration.

The fighter model was coupled to the tail of the bomber by a hinged joint which permitted freedom in pitch between the models. A locking device by means of which the coupling could be made rigid or free in flight was installed on the models. Figure 1 shows the general arrangement and operation of this device which consisted of a locking brake located beneath the tail of the bomber and a connecting rod which extended through the brake and which was connected to the fighter model by a pin joint. When the coupling was free, relative pitching of the fighter model with respect to the bomber caused the connecting rod to slide back and forth in the locking brake. When the coupling was made rigid, the connecting rod was restrained from moving fore and aft so that the fighter model was prevented from rotating about the hinge. The connecting rod was restrained from moving by a friction surface in the locking brake. Small springs were provided to hold the plates apart when the brake was not being used. Compressed air was supplied to the model from the control room of the tunnel through a small flexible tubing which trailed from the model. This arrangement made it possible to change from the freely coupled to the rigidly coupled combination during a flight and thereby permitted a direct comparison of the behavior of the two configurations.

The coupled configurations were controlled with the control surfaces of the bomber model. The control surfaces of the fighter model were fixed. The models were controlled longitudinally by the pilot who actuated the elevator surface of the bomber in the manner described in reference 1. The models were controlled laterally by an autopilot, similar to that described in reference 3, which was sensitive to displacements in bank, yaw, and sidewise position. Although this system actuated the ailerons of the front model only, both models were stabilized laterally because the coupling was rigid in roll and yaw.

TESTS

The flight tests were made for a range of bomber center-of-gravity locations for the bomber alone, the rigidly coupled combination, and the freely coupled combination. For each of these configurations, the bomber center-of-gravity location was moved rearward in progressive steps from the 0.15-mean-aerodynamic-chord station to the point at which the configuration became unflyable. All the bomber center-of-gravity locations presented in this paper are referred to the mean aerodynamic chord of the bomber wing. The fighter center-of-gravity location remained fixed at the quarter chord of the mean aerodynamic chord of the fighter wing.

All the flight tests were made at an airspeed which corresponded to a lift coefficient of 0.7 for the bomber model alone. The coupled combinations were trimmed so that each model supported its own weight at this speed. In order to trim the combination, the fighter model was coupled freely to the bomber model which was already trimmed to fly at the proper speed and the elevator of the fighter model was then trimmed to make the combination fly at this speed. The elevator of the fighter model was left in this position for all the flight tests and the bomber elevator was used to trim the combinations for the various center-of-gravity positions. In order to insure that each of the models was supporting its own weight, for the rigidly coupled combination, the combination was always taken off in the freely coupled condition and the coupling was made rigid after the models had assumed their trim attitude.

Force tests were made with the bomber and fighter models alone and with the rigidly coupled combination in order to provide static stability data for use in the analysis of the flight-test results. The coefficients for the bomber and fighter models were based on the areas and mean aerodynamic chords of the individual models. The coefficients for the rigidly coupled combination were based on the combined areas of the bomber and fighter wings and on the mean aerodynamic chord of the bomber wing. The pitching-moment data for the individual models were referred to the quarter chord of the mean aerodynamic chord of the wings of the individual models. The pitching-moment data for the rigidly coupled combination were referred to the combination center-of-gravity location (0.63 mean aerodynamic chord of the bomber wing) which resulted from locating the center of gravity of the individual models at the 0.25-mean-aerodynamic-chord station of the wings of the individual models. In the force tests of the rigidly coupled combination, the difference between the pitch angles of the fighter and bomber models was 0° which was within the range of angles observed in flight tests (0° to 2°). The force tests were made at a dynamic pressure of 3.0 pounds per square foot. The test Reynolds number, based on the mean aerodynamic chord of the bomber wing, was about 220,000.

RESULTS AND DISCUSSION

The results of the model flight tests are presented in table II in the form of qualitative ratings for the flight behavior of the models for the three test configurations. In this table a graphical illustration of the variation of flight behavior with bomber center-of-gravity position is shown. The table heading is therefore arranged to represent a scale of center-of-gravity positions. Center-of-gravity positions for which the force tests indicate neutral static longitudinal stability for the bomber alone and for the rigidly coupled combination are indicated by hatched lines in the table. The force-test data from which these aerodynamic centers were determined are presented in figure 2 for the bomber model alone and for the rigidly coupled combination. The accuracy of the force-test results for the fighter model presented in figure 2 are considered doubtful because the forces on the model were so small that they could not be measured with a satisfactory degree of accuracy on the free-flight-tunnel balance.

Bomber Alone Tests

The qualitative flight-behavior ratings of table II show that, as would be expected, the flight behavior of the bomber model was satisfactory at the more forward center-of-gravity locations but became progressively less satisfactory as the center of gravity was moved rearward. The motions of the model with the various center-of-gravity locations were similar to those described in reference 4. As pointed out in this reference, the motions became more jumpy and unsteady as the center of gravity was moved rearward. When the center of gravity was somewhat behind the point indicated by the force tests to be the aerodynamic center, the motion appeared to be an aperiodic divergence. The model tended to nose up or down, depending on the direction of the initial disturbance, and pitched so fast that it could not be controlled.

Freely Coupled Combination

The results of the flight tests of the freely coupled combination presented in table II show that, for any particular bomber center-of-gravity location, the flight behavior of the combination was about the same as that of the bomber alone. In fact, the flight behavior of the freely coupled combination seemed identical with that of the bomber model alone except that in addition to the normal longitudinal modes of motion discussed in reference 4, there was a heavily damped short-period pitching oscillation of the fighter model relative to the bomber model. This oscillation was so heavily damped that it only showed up momentarily after large abrupt disturbances such as those resulting from an elevator control.

Rigidly Coupled Combination

The qualitative flight-behavior ratings of table II show that for any given bomber center-of-gravity position the flight behavior of the rigidly coupled combination was markedly worse than that of either the bomber alone or the freely coupled combination. In fact, the rigidly coupled combination was violently unstable over a wide range of bomber center-of-gravity locations for which the other configurations were completely stable.

The force-test data of figure 2 indicate that the reason that the dynamic behavior of the rigidly coupled combination was less satisfactory than that of the bomber alone was that, for a given bomber center-of-gravity location, the rigidly coupled combination was much less stable statically than the bomber alone at the flight-test lift coefficient. Inasmuch as the individual centers of gravity of the bomber and fighter remained unchanged ($0.25\bar{c}$) for the force tests of each of the individual models and of the rigidly coupled combination, the relative static stability of the two configurations is shown directly in this figure. As pointed out previously, the center of gravity of the combination was located at 0.63 mean aerodynamic chord when the centers of gravity of the individual models were located at the quarter-chord station of their individual mean aerodynamic chords. Some simple calculations of the static stability of the rigidly coupled combination indicated that, because of the downwash of the bomber on the fighter, the aerodynamic center did not move rearward as far as did the center of gravity when the fighter was coupled to the bomber. This reduction in stability would generally result unless the wing loading of the fighter were much less than that of the bomber.

Since the flight-test technique consisted of taking off the models in the freely coupled condition and making the coupling rigid after steady flight was attained, a direct comparison of the behavior of the two coupled configurations could be obtained. This test technique also made it possible to obtain good flight-test data for the rigidly coupled combination even when this configuration was unstable. The instability of the rigidly coupled combination for bomber center-of-gravity positions of 0.25 and 0.30 mean aerodynamic chord was apparent in the form of an aperiodic divergence. If the models started to nose down after the coupling was made rigid, they diverged so rapidly that they could not be controlled. If the models started a nose-up divergence when the coupling was made rigid, however, they simply trimmed up to the higher lift coefficient and were stable. The reason for this behavior can be seen from figure 2 which shows that although the slope of the pitching-moment curve for the rigidly coupled combination was unstable at lift coefficients below 0.8, it was stable at lift coefficients above 0.9. This change in static stability at high lift coefficients was apparently caused by a variation in the rate of change with angle of attack of the downwash of the bomber on the fighter. Even though the models could be flown satisfactorily at lift coefficients above 0.9, the behavior of the models was considered unsatisfactory since they could not be flown continuously at lift coefficients below 0.8 because of the static instability in this lift coefficient range.

CONCLUSIONS

The results of the model flight investigation to determine the longitudinal flight behavior of a tandem bomber-fighter coupled-airplane configuration for the cases of rigid-coupling and free-to-pitch coupling may be summarized as follows:

1. For any given position of the bomber center of gravity, the flight behavior of the freely coupled combination was about the same as that of the bomber alone.

2. For any given position of the bomber center of gravity, the flight behavior of the rigidly coupled combination was definitely inferior to that of the bomber alone or the freely coupled combination. In fact, the rigidly coupled combination was violently unstable over a wide range of center-of-gravity locations for which the freely coupled combination and the bomber model alone were stable.

3. Analyses of force-test data for the models indicate that the reason that the dynamic behavior of the rigidly coupled combination was less satisfactory than that of the bomber alone was that, for any given bomber center-of-gravity location, the downwash of the bomber on the fighter caused a reduction in static stability of the combination.

Because of this downwash, the aerodynamic center did not move as far rearward as the center of gravity when the fighter was coupled to the bomber.

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TABLE I

PHYSICAL CHARACTERISTICS OF THE FIGHTER AND BOMBER MODELS

	Bomber	Fighter
Wing:		
Span, ft	4.00	1.56
Area, sq ft	2.67	0.36
Mean aerodynamic chord, ft	0.70	0.25
Sweep, 50 percent chord line, deg	0°	0°
Dihedral, deg	5	0
Aspect ratio	6.00	6.67
Taper ratio	0.5	0.3
Airfoil section	Rhode St. Genese 35	Rhode St. Genese 35
Incidence	0°	0°
Horizontal tail:		
Span, ft	1.63	0.57
Area, sq ft	0.63	0.07
Aspect ratio	4.23	4.80
Taper ratio	0.54	0.37
Weight, lb	10.33	1.03
Tail length, ft	2.0	0.70

TABLE II

QUALITATIVE RATINGS OF LONGITUDINAL FLIGHT BEHAVIOR FOR THE THREE TEST CONFIGURATIONS

Configuration	Flight-behavior rating[1]										
	Bomber center-of-gravity location, percent mean aerodynamic chord of bomber wing										
	15	20	25	30	35	40		45		50	
Bomber alone	A	A	A	B	B	C			C	D	
Freely coupled combination	A	A	A	B	B	C	C	C	C	C	D
Rigidly coupled combination	C	C	D	D							

[1]Flight-behavior ratings:

- A Very stable and easy to fly } Satisfactory
- B Stable and fairly easy to fly } Satisfactory
- C About neutrally stable and difficult to fly } Unsatisfactory
- D Unstable and unflyable } Unsatisfactory

Static longitudinal stability indicated by force tests $\left(\text{negative } \frac{\partial C_m}{\partial C_L}\right)$ ← | → Static longitudinal instability indicated by force tests $\left(\text{positive } \frac{\partial C_m}{\partial C_L}\right)$

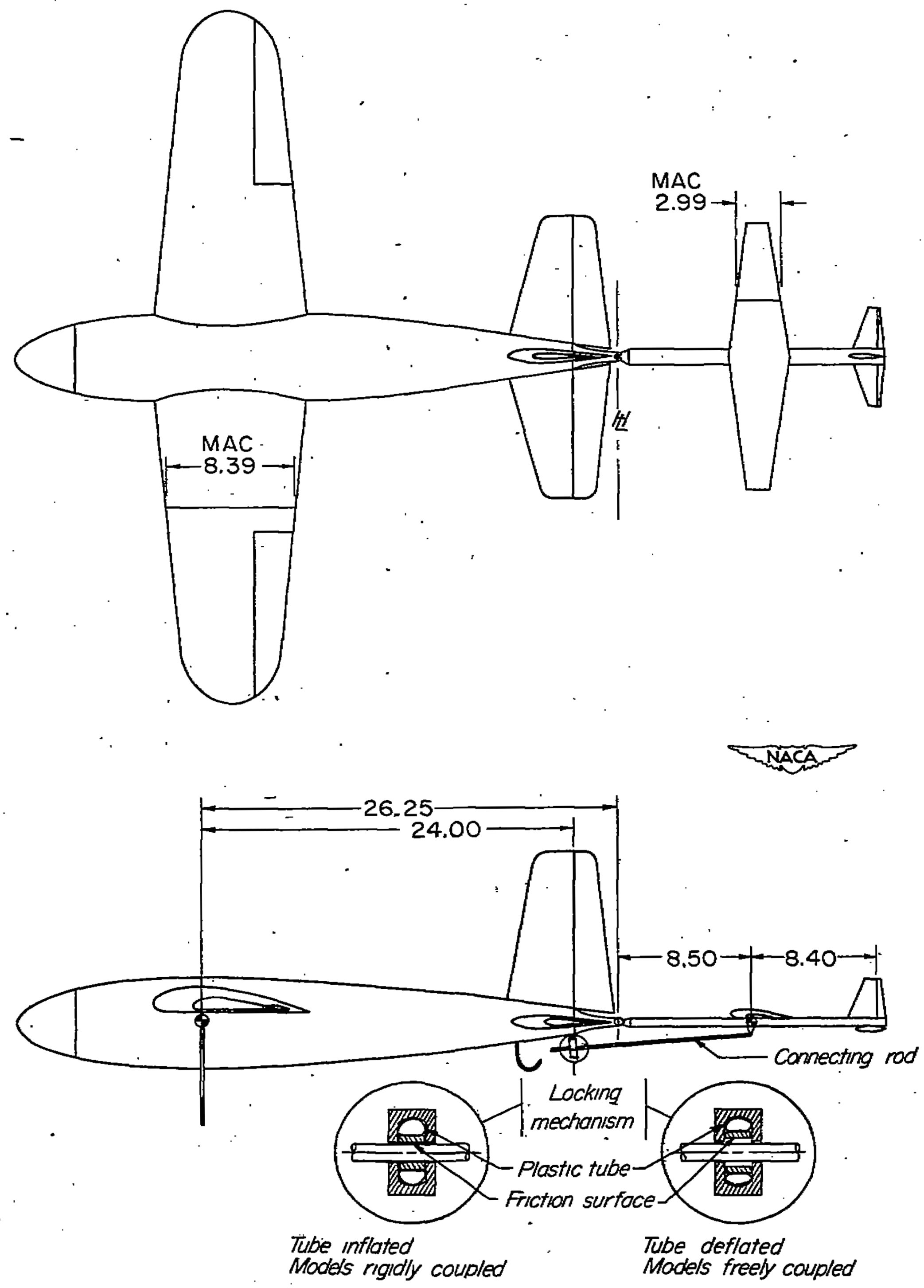

Figure 1.- General arrangement of tandem-coupled bomber-fighter model used for the tests. (All dimensions in inches.)

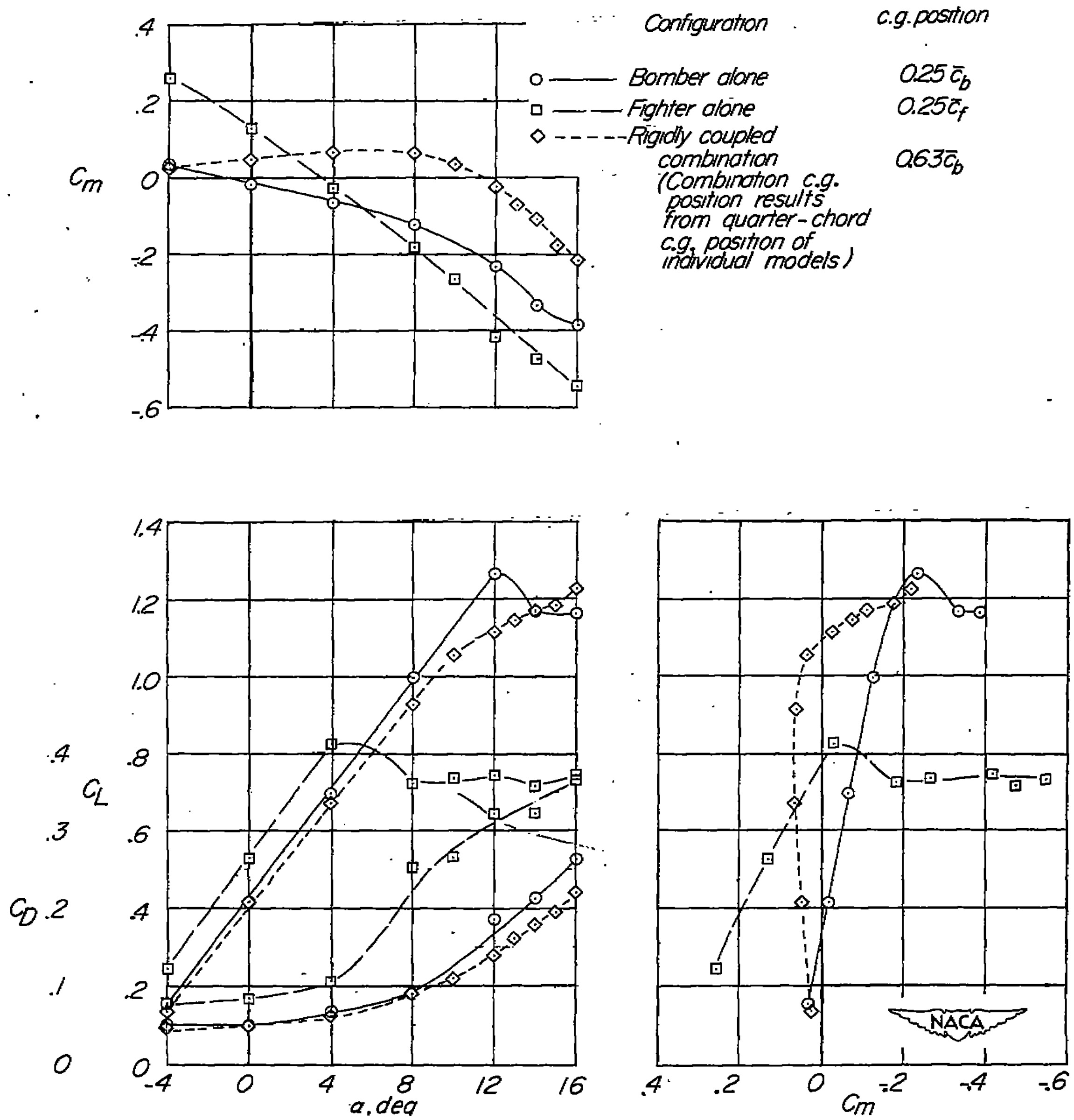

Figure 2.- Lift, drag, and pitching-moment characteristics of the bomber model alone, the fighter model alone, and the rigidly coupled combination. Elevator angles and angle of pitch between the bomber and fighter models are zero. Coefficients of the rigidly coupled combination are based on the areas of the bomber and fighter wings and on the mean aerodynamic chord of the bomber wing.

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